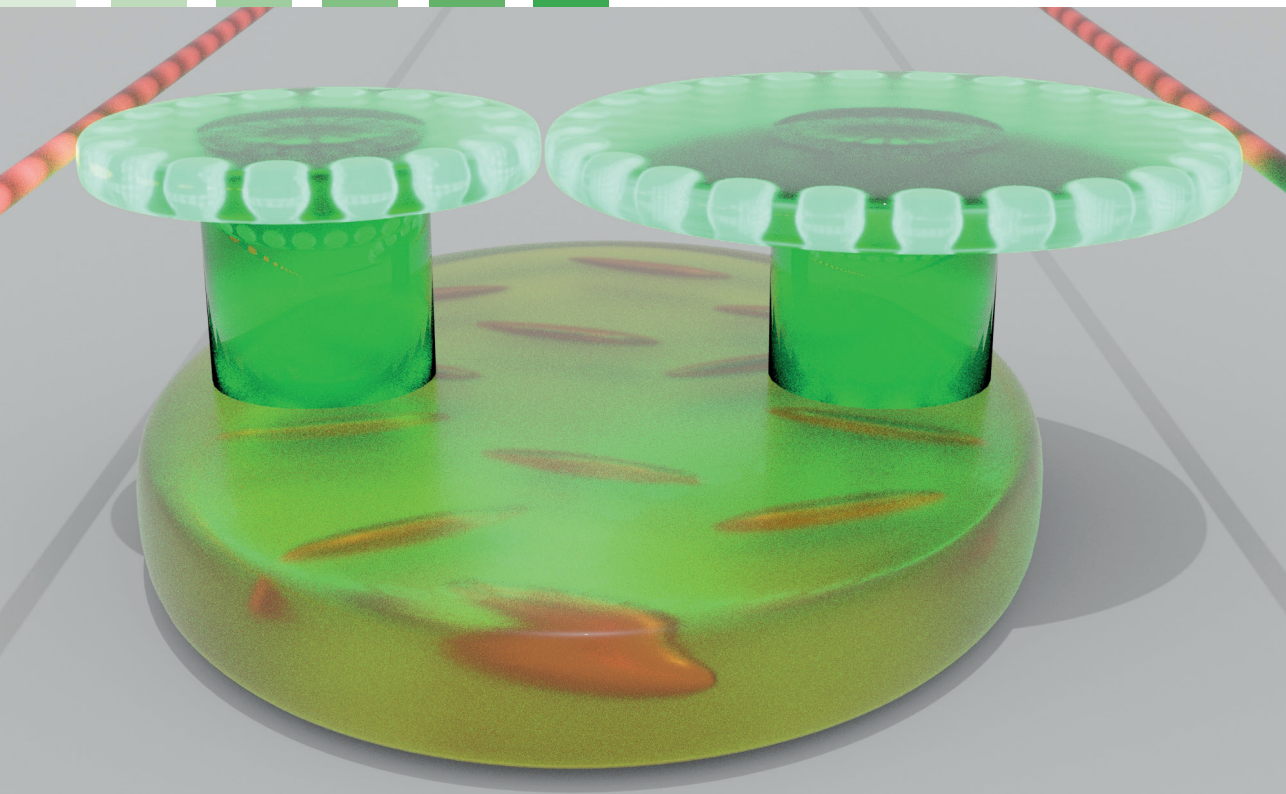


Tunable photonics based on whispering gallery resonators on an all-polymeric chip-scale platform

Simon Woska



Tunable photonics based on whispering gallery resonators on an all-polymeric chip-scale platform

Zur Erlangung des akademischen Grades eines

DOKTORS DER NATURWISSENSCHAFTEN

von der Fakultät für Physik
des Karlsruher Instituts für Technologie (KIT)

genehmigte

DISSERTATION

von

M.Sc. Simon Woska
aus Mühlacker

Tag der mündlichen Prüfung : 03.12.2021

Referent : Prof. Dr. Heinz Kalt

Korreferent : Priv.-Doz. Dr. Michael Hetterich

Prüfungskommission:

Prof. Dr. H. Kalt
Priv.-Doz. Dr. M. Hetterich
Prof. Dr. D. Hunger
Prof. Dr. C. Rockstuhl
Prof. Dr. J. Schmalian



Karlsruhe Institute of Technology (KIT)
Institute of Applied Physics
Wolfgang-Gaede-Straße 1
76131 Karlsruhe
Germany

Research group Prof. Dr. Heinz Kalt: <http://www.aph.kit.edu/kalt>

Simon Woska
simon.woska@kit.edu simon.woska@web.de

This work has been financially supported by the Karlsruhe School of Optics and Photonics (KSOP).



<http://www.ksop.de>

Berichte aus der Physik

Simon Woska

**Tunable photonics based on whispering gallery
resonators on an all-polymeric chip-scale platform**

Shaker Verlag
Düren 2022

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Zugl.: Karlsruhe, Karlsruher Institut für Technologie, Diss., 2021

Copyright Shaker Verlag 2022

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publishers.

Printed in Germany.

ISBN 978-3-8440-8472-6

ISSN 0945-0963

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren

Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9

Internet: www.shaker.de • e-mail: info@shaker.de

Contents

1	Introduction	1
2	Whispering gallery modes in photonic building blocks	5
2.1	Whispering gallery modes and their figures of merit	5
2.2	Spatial mode structure of WGMs in disk-shaped resonators	11
2.3	Photonic applications based on WGMs	17
3	Fiber-transmission spectroscopy of whispering gallery modes	21
3.1	Basics of fiber-transmission spectroscopy	21
3.2	Fiber-transmission spectroscopy using two optical fibers	30
3.3	Polarization-sensitive fiber-transmission spectroscopy	35
4	Fabrication of chip-scale tunable photonic building blocks	41
4.1	Liquid crystal elastomers as chip-scale actuators	42
4.2	Fabrication of chip-scale substrates from LCE	49
4.3	3D laser printing of rigid elements on chip-scale LCE substrates . . .	58
4.4	3D laser printing of micro-scale photonic elements from LCE	64
4.5	Assessment of the developed fabrication processes	71
5	Full spectral tunability of modes in actuating resonators	73
5.1	Basics of spectral tuning of WGMs	73
5.2	Tuning potential of WGMs in LCE resonators	75
5.3	Full spectral tunability of modes in LCE resonators	78
5.4	Assessment of the spectral tunability of WGMs	87
6	Tunable coupling of modes in chip-scale photonic molecules	89
6.1	Basics of variable evanescent coupling of WGMs	90
6.2	Analytical description using coupled-mode theory	93
6.3	Tunable coupling determined from resonance splittings of supermodes	98
6.4	Chip-scale photonic molecules as tunable add-drop filters	103
6.5	Assessment of the tunable coupling of photonic molecules	111

7	Conclusion and outlook	115
A	Samples and fabrication process parameters	119
A.1	List of chemicals	120
A.2	Micro-scale LCE resonators for spectral tuning	120
A.3	Actuating chip-scale LCE substrates	124
A.4	LCE-PMs for tunable coupling	126
A.5	Reference WGM resonators from PMMA	128
B	Additional data on tunable LCE resonators	131
B.1	Real-time investigation of the resonator radius	131
B.2	Preferential field orientations of WGMs in LCE resonators	133
C	Additional data and calculations on tunably coupled LCE-PMs	135
C.1	Real-time investigation of the inter-cavity distance	135
C.2	Spectral shifts of WGMs in LCE-PMs under thermal actuation	137
C.3	Spectra of transferred intensity in add-drop configuration from CMT	139
C.4	Impact of intrinsic losses on the maximum intensity transfer in add-drop configuration	142
C.5	Normalization of the intensity transfer in add-drop configuration on fiber-resonator couplings	143
D	Measurement data	147
	List of publications	149
	References	153
	Closing words	177